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Measurement of Forage Intake and Digestibility in an Intensive Grazing System

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INTRODUCTION

The methods used to determine forage intake and digestibility in grazing ruminants on pasture are virtually the same for both extensive and intensive grazing systems. In order to make nutritional decisions it is critical that some accurate assessment of the daily dry matter (DM) consumed by the animal be made. Accurate measurement of dry matter intake (DMI) is necessary for application of nutritional requirements to achieve a desired animal response. It is vital for diet formulation relative to determining animal performance (Burns et al., 1994).

The measurement of DMI integrates a number of factors such as plant chemical properties, plant and animal physical characteristics, and animal physiological processes. Animal physiological processes are dependent on animal species, breed, type, gender, and production status. Forages generally have sufficiently high fiber concentrations that physically limit intake via distention before energy demands are met (Burns et al., 1994). High quality pastures can be similar to concentrate feeds and intake may be limited by nutrient balance (Fisher, 1990; Poppi et al., 1990). In physical limitation, the rate that forage exits the rumen becomes an important factor in daily intake regulation. The extent and rate of plant tissue comminution upon initial mastication and through subsequent rumination and digestion by rumen microflora greatly influences digesta passage and the time interval between meals (Owens and Goetsch, 1986). Dry matter intake of forage is often limited by the ease with which a diet can be consumed and the residence time of the particles in the digestive tract. The diet selected is forage species-specific and altered by plant maturity and morphology (Blaser et al., 1986).

In addition to physical limitations on intake, there are metabolic controls termed chemostatic, lipostatic, and thermostatic. The chemostatic effect limits intake of animals on diets high in digestible energy concentration, the lipostatic effect limits intake as excessive body fat accumulates, and the thermostatic effect adjusts intake upward as environmental temperatures decline and downward as temperatures increase. These physical and metabolic regulations function simultaneously in controlling daily DMI (Forbes, 1986; Ketelaars and Tolkamp, 1992). In an intensive grazing setting, these factors regulating DMI must be recognized and considered in diet selection because high DMI is a requisite for high daily performance (Burns et al., 1994).

Estimates of DMI of the grazing animal are complicated because there is no straightforward way to measure daily DMI. The DM available to the grazing animal consists of the herbage mass (HM) present over the total land area to which the animal has access. The animal determines the quality of its diet through selective grazing and quantity consumed of that diet at each meal. The eating behavior of ruminants has been clearly characterized as selective, with a strong preference for

green leaf and against dead and stem tissues (Minson,1981). Greater selectivity by the animal for leafy tissue from within the bounds of forage on offer will generally result in a higher quality diet and a greater DMI (Burns et al., 1994).

In an intensive grazing setting, indirect methods (inert markers) have evolved to estimate DMI and permit relative comparisons of DMI among pasture treatments. The accuracy of these methods in estimating DMI resides with the marker methodology in estimating fecal output and in obtaining an accurate assessment of digestibility of the diet consumed (Burns et al., 1994).

An assay to determine the potential DMI of a forage should reflect the animal's physiological status and diet selection without restrictions to feeding level. Estimates of DMI of a forage, other than at unrestricted levels of feeding, provide some integration of diet selectivity and lack of satiety (Burns et al., 1994).

A method that adequately estimates DMI of grazing animals is essential to fully utilize the value of pasture research but continues to be elusive (Burns, 1994). Because the free grazing animal obtains its daily intake of a diet selected only from the forage offered, the ideal method should incorporate both diet quality and the daily (24 hour) quantity of the diet consumed. Accurate estimates of intake would have major implications on the recommendations provided to producers regarding the quantity of HM needed relative to the desired daily animal response and expected productivity per unit land area (Burns, 1994).

The assessment of pasture nutritive value in grazing trials is generally achieved by the comparison of average daily weight gain or milk production per animal. This value provides a long-term and direct integration of the quantity (intake), quality (digestibility), and utilization (conversion) of the diet consumed for each treatment and is an expression of digestible DMI. Unfortunately, DMI, as such, is not generally determined. By definition, daily DMI of free-grazing animals can only be obtained directly by either weighing animals continuously or before and after each grazing event, or through monitoring grazing behavior.

DIRECT MEASUREMENTS OF FORAGE INTAKE

Weighing Animals

One of the most direct methods of determining intake is to weigh animals during eating (Horn, 1981) or before and after they eat. A direct method called the Animal Weight Telemetry System (Horn, 1981), based on the use of pressure transducers affixed under each hoof of the animal and held in place by a boot, has been developed. This approach requires large investments in equipment and sophisticated computer software and has not been used in practice. Weighing animals to estimate intake may require appropriate adjustments for losses (respiration, defecation, urination, etc.) and for non-forage intake (supplemental minerals, water, soil, etc.) during grazing. This has obvious limitations in most grazing settings but has been used successfully when ingestive behavior is of interest and grazing periods can be of limited duration (Penning and Hooper, 1985; Penning et al., 1991). This technique has been most often used with sheep, but can be used with larger ruminants as well. The limitation is the short-term nature of these measurements and the need to account for weight loss due to defecation and urination.

Differences in Herbage Mass

The difference in HM before and after grazing is sometimes used to estimate intake. The reduction in HM observed in a paddock due to grazing may be divided by the product of the number of animals and days grazed. This value may be assumed to be equal to the daily intake per animal. Problems with this technique can be minimized with management and sufficient labor (Meijs et al., 1982). The assumption that the decline in HM is entirely due to consumption of forage is often an overestimation because of trampling or other removal of forage from the harvested sward. To determine HM, forage is cut and weighed from a sample area prior to grazing. The cutting height is seldom low enough to include all of the forage that may have been trampled. Using a low cutting height minimizes this problem but may result in the death of the sward in the sampled areas. Excessive soil contamination by either trampling or when harvesting, or both, may require adjustment for ash, and results may need to be expressed on an organic matter basis.

If HM is used to estimate forage intake, consideration of the growth of the sward during grazing is important. Growth of the sward can result in an underestimation of intake. To minimize these problems, either the grazing period must be kept short (1 to 3 d) or cages should be placed in the pasture to prevent grazing in selected sample areas and used to estimate the growth rate of the pasture for the period in question. The growth of the forage in the cage may not be equal to the growth in the rest of the paddock if the time period is too long (> 7 to 10 d). However, adequate growth must occur or the sampling variance in the selected areas will prevent a sufficiently precise estimate of growth.

The most serious limitation of these differenct methods is the sampling required to provide an adequate estimate of the change in HM. Often, it is not possible to obtain the number of samples needed to make the estimates as reliable as desired.

OBJECTIVE ASSESSMENTS

Sward Cutting Techniques

Herbage mass in a sward can be determined by cutting the forage in a carefully measured area to an established cutting height and weighing it, thus, the forage available in the entire sward can then be estimated. Animals are allowed to graze the entire sward, and animals are removed and another area is cut to the same height as the initial cutting. The forage intake is the difference between the forage available before and after grazing as determined by the pregrazing and postgrazing cutting and weighing. The question with this method is how to cut the forage and remove it, especially if numerous samples are desired. If the number and size of the swards is small and the grazing pressure is moderate to high, then the amount of forage cut and removed for weighing is manageable by a person cutting the forage with manual shears. However, if the sample area is large and the grazing pressure is such that forage accumulates in the swards, then some means of mechanical cutting is desired. Meijs et al. (1982) discussed methods of using a sickle mower or a lawn mower to cut and remove forage from the sample area in a sward. It is critical that the cutting height, for both a sickle type mower or lawn mower, be the same for each sample and for the pre- and postgrazing cuts. Also, the lawn mower cannot deal with tall forage, so the

plot may have to be cut first with a sickle mower and cut postgrazing with the lawn mower. In this latter situation, both the sickle and lawn mower must be set to cut at the same height.

Sward Stick Method

Some researchers estimated HM by taking measurements of height and density of the forage and then calibrated these parameters against actual HM by cutting a defined area of the sward and weighing. Height was defined as the mean height of the forage and density was defined by Bakhuis (1960) as percentage ground cover and estimated by point quadrant or visual appraisal. By determining HM before and after allowing animals to graze an area, an estimate of forage intake is obtained. Earle and McGowan (1979) described the use of the weighted disk grassmeter (sward stick) which integrated the measurement of height and density. A sward stick is relatively simple in design. It consists of a Plexiglas square of exact dimensions with a hole in the center allowing it to slide up and down a length of pipe graduated in cm. One end of the pipe is placed on the ground in the pasture and the Plexiglas plate is allowed to rest on the forage. The height where the plate rests is then read along the pipe, and the forage available in the sward is determined by comparing average plate resting height of several samples to a calibration table. Dr. James Russell and others at Iowa State University have developed a method of estimating forage yield in summer grass and legume pastures which incorporates a sward stick. The cost of the device is relatively low and the precision of the measurements appears to be rather good, which explains why the method has increased in popularity. Russell is quick to point out that the measurements from the sward stick are highly correlated to the yield of live dry matter, not total dry matter. Adjustments to this value may be made to account for sward structure, selectivity of animals, trampling, season, grazing method and growth of forage. The sward stick is particularly useful because animals in a pasture situation primarily select live dry matter for consumption while grazing. The value obtained from the sward stick is useful in determining the length of time a paddock could be grazed at a given stocking rate (Russell et al., 1994). In talking with Dr. Russell, he indicated that the calibration curve which he developed at Iowa State University for the device appears to be fairly robust. He said other researchers had built sward sticks based on his design, and they had found the measurements obtained to be relatively precise across pastures containing various forage species of differing morphology.

Earth Plate Capacitance Meter

Burns et al. (1981) have described the application of an earth-plate capacitance meter to determine plant growth and animal intake. In general, the researchers found such a meter to be relatively cheap to construct and precise in terms of measurements. However, the device must be recalibrated periodically to adjust for differences in forage DM. Herbage mass can also be estimated from capacitance after having first calibrated the capacitance measure with actual HM by cutting and weighing (Meijs et al., 1982). The device does not work on dry forage. The meter measures the change in capacitance caused by vegetation introduced into a capacitance system. The change in capacitance is directly proportional to HM and is registered on a digital display connected to the measuring head of the meter (Meijs et al., 1982).

Animal Behavior

The activity of ingestive intake has been suggested as a method of estimating daily DMI (Coleman et al., 1989). Monitoring grazing behavior requires an estimate of grazing time, number of bites (movements that sever forage) and bite weight or number of ingested boli and ingested boli weight (Hodgson, 1982; Demment et al., 1987). This method is imperfect but has the following attributes consistent with the ideal approach: the animals may be relatively undisturbed, it is applicable to most pasture conditions, once the procedure is developed measurements are relatively easily taken, laboratory analyses are minimal, and the cost of the monitoring device is reasonable. Progress on this approach has been encouraging (Luginbuhl et al., 1991), but direct approaches are rarely used because of cost and limited equipment availability. Quantification occurs through the product of bite size x rate of biting x grazing time (Hodgson, 1982; Demment et al., 1987). Mechanical methods for short-interval measurements have been reviewed (Hodgson, 1982), but recent advances have occurred through automation to aid quantification. A battery powered meter developed by Beauchemin et al. (1989) records total chewing time per day, time spent ruminating, and number of boli ruminated. The system operates based on strain gauges held against the animals jaw area by a halter. The gauges record jaw movement while chewing. The information was relayed to a remote computer where the it was digitized and stored on a PC for further summary. Automation of data collection and summaries of grazing behavior is the major advancement over the frequently used mechanical vibracorder (Hodgson, 1982).

A modification of the stall chewing meter developed by Luginbuhl et al. (1987) has been field tested with the grazing animal and provides total grazing time, rumination time, resting time, number of boli ruminated, total jaw movements, and number of intake bites (Luginbuhl et al., 1991). Eating chews can be calculated by difference between total jaw movements and eating bites plus ruminating chews.

The major factor limiting this technology for estimating DMI is obtaining an acceptable estimate of bite size or DMI per bite. Forwood et al. (1985) developed a conductivity transducing cannula that can provide an accurate reading of the number of boli swallowed. An estimate of boli weight (DM) from direct boli collection, coupled with intake bites per boli (Forbes, 1988), would provide an estimate of DMI per bite. If the estimate of bolus weight could be obtained within reasonable error, then a direct estimate of DMI is feasible from grazing behavior. Although limited, data indicate that boli weight may be dependent on animal weight, forage species, and canopy morphology (Forwood et al., 1991).

SUBJECTIVE ASSESSMENTS

Visual Appraisal

Meijs et al. (1982) stated that HM could be estimated by visual appraisal. It is important that the person making the observations make several observations throughout the pasture following a period of intensive training based on repeated checks by cutting and weighing (Pechanec and Pickford, 1937). One must consider whether the lower accuracy of this method is acceptable in each usage in comparison to the lower cost of the method.

The mind possesses a capacity to integrate multiple factors that are difficult to quantitate with instrumentation (Burns et al., 1994). In a study comparing preference for six *Pennisetum* species,

Burns et al. (1978) devised a relative preference score by assigning a residual herbage score from 1=not grazed to 10=grazed to stubble (10 cm). Because all forages had similar heights at time of grazing, the residual forage provided an estimate of forage intake.

A major concern in using subjective assessments centers on the validity of the process compared with data obtained by objective methods. Since subjective data are generally not continuous, special statistical procedures should be used to aid interpretation (Schiffman et al., 1981). Subjective data may also contain both treatment effects and observer bias which cannot be separated.

Observer bias arises from memory carry-over such that scores assigned to plots in one replicate, or at a previous evaluation, may unknowingly influence subsequent scores. Meijs et al. (1982) identified the sources of bias inherent in visual appraisal, other than bias in cutting reference areas, as the following: 1) fatigue - after three hours or more of pasture examination observers tend to underestimate or overestimate HM, 2) lack of sufficient training - untrained observers tend to overestimate tall growing swards and underestimate dense swards, 3) idiosyncrasy of observers - some trained observers tend to persistently overestimate or underestimate HM. By monitoring the above possible sources of error, producers and researchers could use visual appraisal as a means of estimating forage available prior to and following grazing of swards and in turn estimate forage intake. Such bias results in artificially reduced variances causing small differences to become significant and may erroneously create differences. Observer bias can be partially prevented through a concerted effort on the part of the observer to score each plot independently and to use multiple scorers. In determining forage intake by subjective means, the researcher should also take subjective measures of forage intake because it provides the researcher an assessment of how capable the observers were in assigning a useful score and provides the experience needed to decide in future studies if subjective scores can be used without objective measurements.

INDIRECT METHODS OF ESTIMATING FORAGE INTAKE

Indirect methods to estimate DMI may seem adequate in theory, but in practice they fall short of the ideal method because of a number of difficulties (Owens and Hanson, 1992). These difficulties take the form of high labor requirements, high frequency of disturbing experimental animals, sources of error that can introduce bias, and the large number of chemical analyses to be conducted (Quiroz et al., 1988; Luginbuhl et al., 1993). In spite of these limitations, indirect methods serve a useful role in estimating intake of grazing animals. Estimating the forage intake of free grazing animals is so difficult that all of the commonly used methods have limitations and consist of various compromises that may introduce error (Owens and Hanson, 1992). While none of the techniques are completely adequate, they have value in specific situations and can yield valuable data.

Determining Fecal Output Directly

Total fecal collection, along with an estimate of diet DM digestibility, has been used to estimate DMI. Total fecal output can be measured directly by the use of a collecting bag. The advantages of collection bags for determining fecal output are that they give rapid results and require only DM and ash determinations (Meijs, 1981). Major disadvantages include significant reductions in

animal performance, incomplete collection of feces due to losses (especially on diets low in DM), distortion of hind legs due to weight of feces in bag, high labor requirement, and influence on grazing behavior. In addition, an estimate of diet quality is required. This technique is more practical with sheep because of the high DM of the feces and the smaller size of the animals.

Determining Fecal Output Indirectly

Fecal output (FO) can be estimated based on the ratio of the quantity of a marker administered to an animal to its concentration in the feces [FO (g/d) = (*m*g of marker administered) / (*m*g of marker per g of feces)]. An estimate of the digestibility of the diet can be obtained and used to calculate DMI [DMI = FO/(1 - diet digestibility/100)]. The DMI equation requires an accurate estimate of diet digestibility and not just a correct ranking of the forages being tested. It is important to keep in mind that the use of inert markers is more appropriate for estimating fecal output than forage intake.

Daily Dosing of an Inert Marker

Administering one or two doses of an inert marker each day is a commonly used method for determining fecal output. This is a labor intensive technique, because each time the animals are dosed with the marker they must be either removed from the pasture and restrained or trained to permit dosing through a rumen cannula. If the animals are restrained, a high labor input is required and the handling is stressful for the animals. Various modifications of equipment and experimental design can reduce animal stress and labor requirements. The stress may alter grazing behavior, fecal output, and forage intake. Also, diurnal variation has been observed in the concentration of marker in feces with animals dosed once daily. This can be reduced by dosing twice daily, but labor requirements and animal stress increase proportionally (Burns et al., 1994). Frequent sampling of feces and marker dosing may be useful in overcoming diurnal variation in marker concentrations. Two fecal samples daily are not always sufficient to estimate the mean marker concentration for the day when diurnal variation is present. Even though there are many difficulties with this procedure, an advantage is that the kinetic properties of the marker do not influence the estimate of fecal output.

Pulse Dosing of an Inert Marker

In contrast to daily dosing, a marker may be administered once to an animal followed by frequent fecal collections in order to characterize the "pulse" in marker concentration found in the feces (Pond et al., 1989). The characteristics of the excretion curve make it possible to estimate rate of digesta passage, mean residence time, and digestive tract fill, as well as fecal output and, with an estimate of digestibility, forage intake (Burns et al., 1994). Rate of passage and mean residence time are just inverses in some analysis methods, but the additional explanatory power of this procedure over the daily dose procedure is substantial in some situations. However, there are more pitfalls with this procedure than with the daily dose. First, this procedure is as labor intensive as the daily dose procedure. While the stress on the animals may not be as great as in daily dosing, the animals are disturbed frequently over the first 2 to 3 d for fecal collections that may require grab sampling. The sampling schedule may alter grazing behavior (Fisher et al., 1986) and, consequently, the kinetic parameters estimated from the excretion curve must be interpreted with

caution. A large number of chemical analyses are required to develop the marker excretion curve, and the complexity of modeling marker flow to calculate kinetic parameters and proper interpretation of the resulting data adds a degree of difficulty (Quiroz et al., 1988; Moore et al., 1992; Luginbuhl et al., 1993). The problem of estimating diet digestibility is as serious a problem with this procedure as it is with daily dosing.

Empirical Estimates

Methods have been developed for grazing animals (steers, cows, calves, and sheep) that utilize animal responses in a back calculation to estimate daily requirements. For example, the effective feed unit (EFU) concept developed by Peterson and Lucas (1968) provides an estimate of the average daily EFU (which can be expressed as digestible DM, gross energy, digestible energy, metabolizable energy, net energy, total digestible nutrients (TDN), etc.) consumed per tester animal. This value can be converted into an estimate of daily DMI, as proposed by Baker (1982), using energy values. In both cases, conversion factors for maintenance and weight gain or loss are required. The EFU is no better than the conversion factors employed.

An innovative approach to estimating intake has been developed (Pienaar and Roux, 1989) utilizing observed in vitro rates of gas production to estimate mean retention time and digestibility. Fecal output and intake are then estimated. This technique is dependent on the availability of the appropriate equipment for measuring gas production. The use of gas production allows for more reliable and stable estimates of digestion rate than the traditional gravimetric procedures.

Alkanes as Internal and External Markers

The use of n-alkanes as markers is somewhat unique in that a combination of an internal and external marker can be used (Mayes et al., 1986). Plant alkanes are found in cuticular waxes and consist of predominantly odd-numbered chains of 25 to 35 carbons. These waxes are relatively indigestible, and, as chain length increases, the percent recovery in the feces increases (Barrowman et al., 1989; Ohajuruka and Palmquist, 1991). Analysis is relatively easy and precise, but requires a gas chromatograph. Since plant alkanes have odd numbered chain lengths, the alkanes with even numbered chain lengths may be fed as external markers. The use of alkanes can provide estimates of both digestibility and fecal output for the calculation of intake. The procedure can even allow for individual animal variation in digestibility of forages (Mayes et al., 1986; Dove et al., 1989a; Dove et al., 1990; Vulich et al., 1991; Bechet and Tulliez, 1992).

A problem has been pointed out (Laredo et al., 1991) that may require some modifications in the most common approach to using alkanes. Forage species contain variable quantities of alkanes, and the concentrations of C33 may be too low in some tropical forages for use as the internal marker. This can require the use of a shorter chain length with a lower percent recovery in the feces and possibly result in errors in calculation of intake. However, the variation from species to species in alkane composition can be used to an advantage by solving a set of simultaneous equations and estimating the species composition of the diet (Dove, 1991).

Controlled Release Devices

Recently, a controlled release device (CRD) has been developed and marketed for the delivery of chromium sesquioxide (Cr_2O_3). The CRD was developed to overcome the difficulties of once or twice daily dosing with Cr_2O_3 and the diurnal variation in output of Cr_2O_3. There are serious problems with CRD. Shortcomings of the CRD include large deviations between observed and manufacturer-specified release rates with both cattle and sheep (Brandyberry et al., 1991; Buntinx et al., 1992), variation in release rates (Buntinx et al., 1992), a feed by CRD interaction (Parker et al., 1989), and an animal by CRD interaction in release rate (Pond et al., 1990). Thus, release rate may be dependent on the particular animal and forage being tested.

DETERMINING FORAGE DIGESTIBILITY IN AN INTENSIVE GRAZING SYSTEM

Sampling Diet and Estimating its Digestibility

Associated with the use of inert markers in estimating DMI of the grazing animal is the requirement of knowing the digestibility of the animal's diet. Obtaining samples that represent the diet of the dosed animals can frequently be the major factor limiting accuracy of the marker technique.

The two basic approaches in obtaining a representative diet are a manual collection of forage by the experimenter or use of surgically altered (rumen or esophageal cannula) animals (Le Du and Penning, 1982). In the former case, the experimenter observes what the animals are grazing and then attempts to mimic their selection manually. This procedure is sometimes criticized for being subjective. The use of animals with either a rumen or esophageal cannula is intended to provide a diet similar to the one consumed by the tester animals. However, biased estimates of the diet of tester animals can result from the use of cannulated animals if adequate sampling is not achieved.

Use of the rumen cannulated animal requires the removal of sufficient rumen contents to expose the cardia. The animal is allowed to graze while the experimenter catches the ingested material as it drops from the cardia with entrance via the rumen cannula. The esophageal cannula has generally replaced the rumen cannula because it requires only removal of the cannula plug to allow collection of extrusa. In both cases, care should be used to avoid contamination of the sample with excess saliva or rumen contents. Saliva should not be drained from the sample because of DM losses (Little, 1972), and samples contaminated with rumen fluid should be discarded. The drying of extrusa for digestibility analyses is best achieved by freeze drying (Le Du and Penning, 1982). Estimates of digestibility can be obtained directly or using internal markers.

In-Vitro or In-Situ Dry Matter Disappearance

After a representative sample is collected, the accuracy of the marker technique resides with the method used to estimate the absolute digestibility of the diet (Burns et al., 1994). The two-stage in vitro bioassay is the method of choice for estimating diet quality and has the broadest application (Le Du and Penning, 1982). Frequently 48 h fermentation values are used, but 72 h values may be more appropriate for C4 grasses when absolute values are important. In either case, in vitro values can also result in serious errors (Holechek et al., 1986; Dove et al., 1990). It is possible to develop regression equations for conversion of in vitro estimates to in vivo. If properly validated, this approach can be used to improve prediction of intake based on fecal output (Burns et al., 1994).

Internal Markers

Internal markers are natural plant constituents that are neither digested nor absorbed by the animal. They can be used to estimate DM digestibility (DIG) of the diet by knowing the ratio of the marker concentration in the diet (Md) and feces (Mf).

DIG, % = 100 - [100 * ([Md]/[Mf])]

Internal markers that have been evaluated by various researchers are silica, lignin, fecal N, chromogen, indigestible neutral detergent fiber, and acid insoluble ash. Silica occurs naturally in forage and is indigestible and should be recovered in the feces. Silica concentrations in forage have been variable and inconsistent and subject to contamination by soil. These problems and a poor recovery of silica in feces have limited its use (Gallup et al., 1945). Lignin is a naturally occurring indigestible portion of the cell wall, and reliable results as an internal marker have been noted (Ellis et al., 1946). Diurnal variation in lignin concentration in the feces can be high, so many samples must be collected and analyzed. Fecal N was associated with forage digestibility (Holter and Reid, 1959), and an equation was developed (Schneider and Flatt, 1975) to determine DM digestibility using crude protein concentration in forage and feces. This method has not been evaluated for many forage species. Chromogens are plant pigments that are completely recovered in the feces. Chromogens, as markers (Reid et al., 1950, 1952), seem best for lush growing forage and least effective for drought or stressed (poorly pigmented) plant tissues. Indigestible neutral detergent fiber (after 144 to 196 h in vitro fermentation) has been successfully used as an internal marker (Lippke et al., 1986). Variable recovery and a recovery by particle size interaction are potential problems with this technique. Acid insoluble ash (ash after acid hydrolysis) has been used as an internal marker in feedlot diets and when grazing (Thoney et al., 1985). However, the concentration in most forages is low requiring analysis of larger samples of forage and feces than with the other markers. Lignin has been the most widely used marker of the ones discussed above. However, an infallible and totally dependable internal marker is not available (Cochran et al., 1986). Such an internal marker would contribute greatly to improving the estimation of diet digestibility and DMI of the grazing animal.

FUTURE CONSIDERATIONS

Plant Material with Low Alkane Concentrations

The longer chain length alkanes are not present in all plant material in high enough concentrations to be useful (Laredo et al., 1991). The use of the shorter chain length alkanes is complicated by a lack of recovery. It may be possible to administer a spectrum of even-numbered alkanes and adjust fecal concentrations of the shorter chain length alkanes to the longest chain alkane. This method would allow an estimation of percent recovery for each alkane as well as multiple calculations of digestibility, fecal output, and intake. This approach was outlined by Mayes et al. (1986) in which two even-numbered alkanes were dosed by a CRD and another by a once daily administration of impregnated paper. The adjustment for percent recovery may make the estimates of diet composition from fecal alkane concentrations with animals grazing polycultures more accurate (Dove, 1991). Adequate fecal sampling to compensate for diurnal variation is as important with this material as it is with the more common markers. Although twice daily dosing has been found

to be sufficient in some cases (Dove et al., 1989a,b), in other cases it has seemed to be inadequate (Dove et al., 1991).

Pulse Dose of Alkanes

There is a possibility that a combination of alkane and pulse dose technologies may result in an increase in the information collected by alkane dose and an improvement in the reliability of the pulse dose technique. An alkane pulse dose has been done (Marais et al., 1992) by both a single dose of cellulose powder and by coating alkane on forage. However, the objectives of that study were not to assess rumen kinetics. Consequently, samples were not analyzed at the later times, so the necessary curve fitting and mathematical analysis were not possible.

Animal Behavior and Intake

The effects of various aspects of animal behavior on grazing intake have been alluded to. For example, we may change the intake of an animal under study by our methods of determining intake. The *ad libitum* intake observed on pasture is an integration of many factors. Herbage mass, plant morphology, forage composition, bite size, biting rate, grazing time, topography, animal class, animal physiological status, environment, animal preference, and the effects of our experimental procedures all influence *ad libitum* intake. It is especially difficult to determine the importance of animal preference on intake (Kenney and Black, 1984; Minson and Bray, 1986; Burns et al., 1988). Although these experiments give some indication as to the relative magnitude of animal preference for one forage over another, the next step is to conduct an experiment comparing two forages that differ only in preference. This will not be an easy experiment to carry out. Kenney and Black (1984) found large differences in preference due to physical form. Physical limitations to intake rate appeared to produce a large preference for the forage with the higher intake rate.

Further research is needed on the effects of preference on intake independent of forage composition and physical form. In order to conduct this research, two forages must be used that have only negligible differences in composition and physical form but substantial differences in preference. If preference for one forage over another is a significant factor affecting intake, perhaps it will be possible to breed for animal preference or plant characteristics that increase intake by altering preference alone (Burns et al., 1994).

Literature Cited

Bakhuis, J.A. 1960. Estimating pasture production by use of grass length and sward density. Netherlands Journal of Agricultural Science. 8:211.

Barrowman, J.A., A. Rahman, M.B. Lindstrom and B. Borgstrom. 1989. Intestinal absorption and metabolism of hydrocarbons. Progress Lipid Res. 28:189.

Beauchemin, K.A., S. Zelin, D. Genner and J.G. Buchanan-Smith. 1989. An automated system for quantification of eating and ruminating activities of dairy cattle housed in stalls. J. Dairy Sci. 72:2746.

Bechet, G. and J. Tulliez. 1992. Estimation of grass intake by lambs with alkanes as markers. Ann. Zootech. 41:85.

Blaser, J.L., R.C. Hammes, J.P. Fontenot, H.T. Bryant, C.E. Polan, D.D. Wolf, F.S. McClaugherty, R.G. Kline and J.S. Moore. 1986. Growth stages of plants, forage quality and animal production. In: Forage-Animal Management Systems. Virginia Agric. Exp. Stn. Bulletin 86-7. p9.

Brandyberry, S.D., R.C. Cochran, E.S. Vanzant and D.L. Harmon. 1991. Effectiveness of different methods of continuous marker administration for estimating fecal output. J. Anim. Sci. 69:4611.

Buntinx, S.E., K.R. Pond, D.S. Fisher and J.C. Burns. 1992. Evaluation of the captec chrome controlled-release device for the estimation of fecal output by grazing sheep. J. Anim. Sci. 70:2243.

Burns, J.C., D.H. Timothy, R.D. Mochrie, D.S. Chamblee and L.A. Nelson. 1978. Animal preference, nutritive attributes, and yield of Pennisetum flaccidum and P. Orientale. Agron. J. 70:451.

Burns. J.C., J.M. Toledo, R.D. Mochrie. 1981. Estimating available forage with the earth- plate capacitance meter. In: J.L. Wheeler and R.D. Mochrie (Ed.) Forage evaluation, concepts and techniques. Proceedings Forage Evaluation and Utilization. Oct. 27-31, 1980. Armidale, NSW. p261.

Burns, J.C., D.H. Timothy, R.D. Mochrie and D.S. Fisher. 1988. Relative grazing preference of Panicum Germplasm from three taxa. Agron. J. 80: 574.

Burns, J.C., K.R. Pond and D.S. Fisher. 1994. Measurement of forage intake. In: G.C. Fahey (Ed.) Forage quality, evaluation and utilization. p502.

Cochran, R.C., D.C. Adams, J.D. Wallace and M.L. Galyean. 1986. Predicting digestibility of different diets with internal markers: Evaluation of four potential markers. J. Anim. Sci. 63:1476.

Coleman, S.W., T.D.A. Forbes, and J.W. Stuth. 1989. Measurements of the plant-animal interface in grazing research. In G.C. Marten (Ed.) Grazing research: Design, methodology and analysis. CSSA spec. Publ 16. CSSA, Madison WI. p. 37-51.

Demment, M. W., E. A. Laca, and G. B. Greenwood. 1987. Intake in grazing ruminants: A conceptual framework. In: Feed intake by beef cattle. OK Agric. Exp Stn MP 121, Oklahoma State Univ., Stillwater. p208.

Dove, H., J.Z. Foot and M. Freer. 1989a. Estimation of pasture intake in grazing ewes, using the alkanes of plant cuticular waxes. In: R. Jarrige (Ed.) Proc. XVI Inter. Grassl. Congr. Nice, France. October 4-11, 1989. Versailles, France. p1091.

Dove, H., R.W. Mayes, M. Freer, J.B. Coombe and J.Z. Foot. 1989b. Fecal recoveries of the alkanes of plant cuticular waxes in penned and in grazing sheep. In: R. Jarrige (Ed.) Proc. XVI Inter. Grassl. Congr. Nice, France. October 4-11, 1989. Versailles, France. p. 1093.

Dove, H., J.A. Milne and R.W. Mayes. 1990. Comparison of herbage intakes estimated from in vitro or alkane-based digestibilities. Proc. N. Z. Soc. Anim. Prod. 50:457.

Dove, H. 1991. Using the n-alkanes of plant cuticular wax to identify plant species in the diet of herbivores. In: M.W. Zahari, Z.A. Tajuddin, N. Abdullah and H.K. Wong (Ed.) Proc. 3rd Int. Symp. Nutr. Herb. August 25-30, 1991. Penang, Malaysia. Malaysian Soc. Anim. Prod. Serdang. Selangor, Malaysia. p58.

Dove, H., R. W. Mayes, C. S. Lamb, and K. J. Ellis. 1991. Evaluation of an intra-ruminal controlled-release device for estimating herbage intake using synthetic and plant cuticular wax alkanes. In: M.W. Zahari, Z.A. Tajuddin, N. Abdullah and H.K. Wong (Ed.) Proc. 3rd Int. Symp. Nutr. Herb. August 25-30, 1991. Penang, Malaysia. Malaysian Soc. Anim. Prod. Serdang. Selangor, Malaysia. p82.

Earle, D.F. and A.A. McGowan. 1979. Evaluation and calibration of an automated rising plate meter for estimating dry matter yield of pasture. Australian Journal of Experimental Agriculture and Animal Husbandry. 19:337.

Ellis, G.H., G. Matrone and L.A. Maynard. 1946. A 72 percent H2SO4 method for the determination of lignin and its use in animal nutrition studies. J. Anim. Sci. 5:285.

Fisher, D.S., J.C. Burns and K.R. Pond. 1986. Sampling effects on grazing behavior in marked forage trials. Agronomy abstracts. ASA, Madison, WI. p141.

Fisher, D.S., J.C. Burns and K.R. Pond. 1990. Modelling physical limitations to intake in ruminant digestion. In: A.B. Robson and D.P. Poppi (Ed.). Proc. third international workshop modelling digestion and metabolism in farm animals. September 1989. Lincoln College. Canterbury, New Zealand. p19.

Forbes, J.M. 1986. The voluntary food intake of farm animals. Butterworths, London.

Forbes, T.D.A. 1988. Researching the plant-animal interface: The investigation of ingestive behavior in grazing animals. J. Anim. Sci. 66:2369.

Forwood, J.R., M.M. Hulse and L.L. Ortbals. 1985. Electronic detection of bolus swallowing to measure forage intake of grazing livestock. Agron. J. 77:969.

Forwood, J.R., A.M.B. da Silva and J.A. Paterson. 1991. Forage and livestock affecting accuracy of electronic intake measurements of grazers. In: Agronomy Abstracts. ASA, Madison, WI. p187.

Gallup, W.D., C.S. Hobbs and H.M. Briggs. 1945. The use of silica as a reference substance in digestion trials with ruminants. J. Anim. Sci. 4:68.

Hodgson, J. 1982. Ingestive behaviour. In J. D. Leaver (Ed.) Herbage intake handbook. The British Grassland Society, Hurley, Maidenhead, Berkshire, UK. p113.

Holechek, J.L., H. Woffard, D. Arthun, M.L. Galyean and J.D. Wallace. 1986. Evaluation of total fecal collection for measuring cattle forage intake. J. Range Manage. 39:2.

Holter, J.A. and J.T. Reid. 1959. Relationship between the concentration of crude protein and apparently digestible protein in forages. J. Anim. Sci. 18:1339.

Horn, F. P. 1981. Direct measurement of voluntary intake of grazing livestock by telemetry. In: J. W. Wheeler and R. D. Mochrie (Ed.) Forage evaluation: Concepts and techniques. Armidale, Australia, 27-31 October 1980, Griffin Press Limited, Netley, South Australia. p367.

Kenney, P.A. and J.L. Black. 1984. Factors affecting diet selection by sheep. I. Potential intake rate and acceptability of feed. Aust. J. Agric. Res. 35:551.

Ketelaars, J.J.M.H. and B.J. Tolkamp. 1992. Toward a new theory of feed intake regulation in ruminants. Causes of differences in voluntary feed intake: Critique of current views. Livestock Prod. Science. 30:269.

Laredo, M.A., G.D. Simpson, D.J. Minson and C.G. Orpin. 1991. The potential for using n-alkanes in tropical forages as a marker for the determinations of dry matter intake by grazing ruminants. J. Agric. Sci. (Camb.) 117:355.

Le Du, Y.L.P. and P.D. Penning. 1982. Animal-based techniques for estimating herbage intake. In: J.D. Leaver (Ed.) Herbage intake handbook. The British Grassl. Soc. Hurley, Maidenhead, Berkshire, UK. p37.

Lippke, H., W.C. Ellis and B.F. Jacobs. 1986. Recovery of indigestible fiber from feces of sheep and cattle on forage diets. J. Dairy Sci. 69:403.

Little, D.A. 1972. Studies on cattle with oesophageal fistulae: The relation of the chemical composition of feed to that of the extruded bolus. Aust. J. Exp. Agric. Anim. Husb. 12:126.

Luginbuhl, J.M., K.R. Pond, J.C. Russ, and J.C. Burns. 1987. A simple electronic device and computer interface system for monitoring chewing behavior of stall-fed ruminant animals. J. Dairy Sci. 70:1307.

Luginbuhl, J.M., K.R. Pond, J.C. Burns, D.S. Fisher, and J.C. Russ. 1991. A computer interface system to monitor the ingestive and ruminating behavior of grazing ruminants. In: Proc. 2nd Grazing Livestock Nutrition Conference. 2-3 August 1991, Steamboat Springs, CO. Oklahoma Agric. Exp. Sta. MP-133, Oklahoma State Univ., Stillwater. p177.

Luginbuhl, J.M., K.R. Pond, and J.C. Burns. 1993. Whole tract digesta kinetics and comparison of techniques for the estimation of fecal output in steers fed Coastal bermudagrass hay at four levels of intake. J. Anim. Sci. 71:(In Press).

Marais, J.P., M. de Figueiredo and D.L. Figenschou. 1992. The behaviour of insoluble n- alkane markers in the rumen. Programme and Proceedings. 31st Annual Cong. of the South African Soc. of Anim. Prod. April 13-16, 1992. Zithabiseni, Kwandebele. South African Society of Animal Production. Germiston, Republic of South Africa. p24.

Meijs, J.A.C. 1981. Herbage intake by grazing dairy cows. Agric. Res. Rep. 909. Centre Agric. Publ. and Documents. Wageningen, Netherlands.

Meijs, J.A.C. , R.J.K. Walters and A. Keen. 1982. Sward methods. In: J.D. Leaver (Ed.) Herbage intake handbook. British Grassland Society. p11.

Minson, D.J. 1981. Nutritional differences between tropical and temperate pastures. In: F.H.W. Morley (Ed.). World Animal Science B1. Grazing Animals. Elsevier Sci. Publ. Co., New York. p143.

Minson, D.J. and R.A. Bray. 1986. Voluntary intake and in vivo digestibility by sheep of five lines of Cenchrus ciliaris selected on the basis of preference rating. Grass Forage Sci. 41:47.

Ohajuruka, O.A. and D.L. Palmquist. 1991. Evaluation of n-alkanes as digesta markers in dairy cows. J. Anim. Sci. 69:1726.

Owens, F.N. and A.L. Goetsch. 1986. Digesta passage and microbial protein synthesis. In: L.P. Milligan, W.L. Grovum and A. Dobson (Ed.). Control of digestion and metabolism in ruminants. Prentice-Hall. Englewood Cliffs, NJ. p196.

Owens, F.N. and C.F. Hanson. 1992. External and internal markers for appraising site and extent of digestion in ruminants. J. Dairy Sci. 75:2605.

Parker, W.J., S.N. McCutcheon and D.H. Carr. 1989. Effect of herbage type and level of intake on the release of chromic oxide from intraruminal controlled release capsules in sheep. N. Z. J. Agric. Res. 32:537.

Pechanec, J.P. and G.D. Pickford. 1937. A weight estimate method for the determination of range or pasture production. J. American Soc. Agron. 29:894.

Penning, P.D., and G.E. Hooper. 1985. An evaluation of the use of short- term weight changes in grazing sheep for estimating herbage intake. Grass Forage Sci. 40:79.

Penning, P.D., A.J. Parsons, R.J. Orr, and T.T. Treacher. 1991. Intake and behaviour responses by sheep to changes in sward characteristics under continuous stocking. Grass Forage Sci. 46:15.

Poppi, D.P., M. Gill, J. France and R.A. Dynes. 1990. Additivity in intake models. In: Proceedings of third international workshop modelling digestion and metabolism in farm animals. Sept. 4-6, 1989. Lincoln College. Canterbury, New Zealand. p29.

Pond, K.R., W.C. Ellis, J.H. Matis and A.G. Deswysen. 1989. Passage of chromium- mordanted and rare earth-labeled fiber: Time of dosing kinetics. J. Anim. Sci. 67:1020.

Pond, K.R., J.M. Luginbuhl, J.C. Burns, D.S. Fisher and S.E. Buntinx. 1990. Estimating intake using rare earth markers and controlled release devices. Proc. 45th Southern Pasture and Forage Crop Improvement Conf. Little Rock, AR. June 12- 14, 1989. National Tech. Info. Ser. Springfield, VA. p73.

Quiroz, R.A., K.R. Pond, E.A. Tolley, and W.L. Johnson. 1988. Selection among nonlinear models for rate of passage studies in ruminants. J. Anim. Sci. 66:2977.

Reid, J.T., P.G. Woolfolk, C.R. Richards, R.W. Kaufmann, J.K. Loosli, L.K. Turk, J.I. Miller and R.E. Blazer. 1950. A new indicator method for the determination of digestibility and consumption of forages by ruminants. J. Dairy Sci. 33:60.

Reid, J.T., P.G. Woolfolk, W.A. Hardison, C.M. Martin, A.L. Brundage and R.W. Kaufmann. 1952. A procedure for measuring the digestibility of pasture forage under grazing. J. Nutr. 46:255.

Russell, J.R. 1994. Construction and use of the ISU sward stick. Unpublished diagram.

Schiffman, S.S., M.L. Reynolds, and F.W. Young. 1981. Introduction to multi- dimensional scaling: Theory, methods, and application. Academic Press, New York.

Schneider, B.H. and W.P. Flatt. 1975. Pasture consumption and digestibility. In: The evaluation of feeds through digestibility experiments. The University of Georgia Press. Athens, GA. p107,178.

Thoney, M.L., B.A. Palhof, M.R. Carlo, D.A. Ross, N.L. Firth, R.L. Quass, D.J. Perosio, D.J. Duhaime, S.R. Rollins and A.Y.M. Nour. 1985. Sources of variation of dry matter digestibility measured by the acid insoluble ash marker. J. Dairy Sci. 68:661.

Vulich, S.A., E.G. O'Riordan and J.P. Hanrahan. 1991. Use of n-alkanes for the estimation of herbage intake in sheep: Accuracy and precision of the estimates. J. Agric. Sci. (Camb.) 116:319.